(54) **Automatic running work vehicle**

(57) An automatically controlled vehicle eg a bulldozer, mower or sprinkler truck has a distance sensor for detecting the vehicle running distance, an orientation sensor 5 for detecting the running direction thereof, and a processing unit for teaching the running course of one travel of the vehicle by sampling the running direction detected by the orientation sensor every predetermined running distance detected by the distance sensor during the travel and for steering the vehicle based on the information of the running course obtained by the teaching of the preceding travel when the follower sensors 101 fail to detect the boundary for a predetermined period of time. The vehicle is taught by driving it round the edge of the area to be treated. It then covers the whole area inside this edge automatically.

Fig. 6

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Fig. 1

Fig. 2

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Fig. 4

Fig. 3

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Fig. 5

Speed change unit

Fig. 6

y-direction

18

17

(x_2, y_2)

(x_1, y_1)

l_0

l_0

4

d

ST (x_0, y_0)

(x_{n-1}, y_{n-1})

(x_n, y_n)

x-direction

Fig. 7

y

(x_1, y_1)

(x_k, y_k)

l_1 l_2 l_3

d

l_k

ST (x_0, y_0)

X

(x_n, y_n)

(x_k, y_k)

Fig. 8

17B

S_2'

S_1'

17

S_1

S_2

17C

17D

17A

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Fig. 9

Start

Initialization

Is teaching started — NO

Yes

Orientation Sensor Subroutine (360°)

address n=0

10

START COUNTER

Count ≧ ℓₐ? — NO

Yes

n = n + 2

reset Counter

Store A/D Xn in — Converted address n

Store A/D Yn in — Converted address n+1

Store final address value N. to address n+1

orientation sampling point coordinates calculating routine

general form calculating routine

section distance calculating routine

Subsequent Control

※

start running

NO

start distance counter

Has sensor 5A or 5B detected boundary

NO

Yes

NO

reset time counter

is reset time up — NO / Yes

follower control

Playback Control

is running distance larger than in preceding travel.

Has sensor 6 detected obstacle — NO

Yes

Obstacle detouring cont.

is teaching completed?

change of direction for turning

Completed — NO

Yes

End

reset distance Counter block transfer to memory

Fig. 10

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```
                    ( Start )
                        |
                 [ Initialization ]
                        |
                        v
                  /  Is  \
         NO <----< Teaching >
                  \Started?/
                        | Yes          orientation
                        |              Sensor
              [                ]       Subroutine
                        |              (360°)
                  [ Address n=0 ]
                        |
                        v
              [ Start Counter ]------ 10
                        |
                        v
                  /        \      NO
                 < Count≧ℓo? >------
                  \        /
                        | Yes
   [ n = n + 2 ]  [ reset Counter ]
         |              |
Store A/D-Converted [          ]
Xn in   address n
         |              |
Store A/D-Converted [          ]
Yn in   address n+1
         |              v
         |        /   Is   \
         -------<  Teaching  >
                  \ Compd. /
                        |
Store final     [              ]
address value
N to address  [                ]  orientation sampling
n+1                     |          Point coordinates
                                   Calculating routine
general form   [              ]
Calculating
routine                |
                [                ]  Section distance
                        |          Calculating routine
Subsequent     [              ]
Control
```

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F i g . 11

Start

Initialization

Start running — NO

Start distance counter

Has sensor 5A or 5B detected boundary — NO

Yes

Reset time counter

NO — Is reset time up — Yes

follower control

Playback Control

Is running distance larger than in preceding travel? — Yes

Has Sensor 6 detected obstacle — NO

Yes

obstacle detouring control

Change of direction for turning

Reset distance Counter block transfer to memory

Completed — NO

Yes

End

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Fig. 12

```
        ┌─────────────────────┐
        │ coordinates calculat-│
        │  ing  Subroutine    │
        └─────────────────────┘
                  │
        ┌─────────────────────┐
        │ store 0 in address 0 │
        │ Store 0 in address 1 │
        └─────────────────────┘
                  │
        ┌─────────────────────┐
        │ n=1 , X₀=0 , Y₀=0    │
        └─────────────────────┘
                  │
        ┌─────────────────────┐
        │ Xn← address 2n data  │
        │ Yn←    "   2n+1  "   │
        └─────────────────────┘
                  │
        ┌─────────────────────┐
        │ quadrant judging     │
        │  Subroutine          │
        └─────────────────────┘
                  │
```

$n = n+1$

$X_n \leftarrow$ address $2n$ data
$Y_n \leftarrow$ " $2n+1$ "

$n = 1, X_0 = 0, Y_0 = 0$

$$\theta = \theta + \tan^{-1} \frac{Y_n}{X_n}$$

$$X_n = X_{n-1} + l_0 \cos\theta$$
$$Y_n = Y_{n-1} + l_0 \sin\theta$$

Store X_n in address $2n$
Store Y_n in address $2n+1$

No ◇ $n+1 \geq N$?

Yes

(RETURN)

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F i g . 13

Obstacle det-
ouring control

Stop
Vehicle

Which of contact
members 6a-6d
turned

Central
member 6b or 6c → NO → Left
turned? Outer member → NO
6a
turned

Yes Yes

Retract predeter-
mined distance

Left
Outer member → NO
6a
turned

Yes

Steer rightward   Steer Leftward

Start
advance

Yes   Is sensor 6
still detecting
obstacle

NO

Playback
Control

Reverse
Steering

Return

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F i g . 14

```
┌─────────────┐
│  Playback   │
│  Control    │
└─────────────┘
       │
┌─────────────┐
│   Stop      │
│  Vehicle    │
└─────────────┘
       │
┌─────────────┐         calculate total
│             │ ─────── travel distance
└─────────────┘         from turning area
       │                to present point
       ▼
Is data stored        ◇ ──── NO ────┐
as to corresponding                  │
travel                               │
distance?                            ▼
       │ Yes                  ┌─────────────┐
       ▼                      │             │
┌─────────────────┐          └─────────────┘
│ Read out θ      │                  │
│ Corresponding to ℓ│                 │
└─────────────────┘          average of
Is orientation    │          running directions
detected by       ▼          Corresponding to most
Sensor 8 in    ◇ ──── NO ──── proximate total
match with        │           travel distance
θ stored          │ Yes    ┌─────────────────┐ is to be
                  │        │ Drive cylinder  │ taken as data θ
                  │        │ 9 to obtain match│
                  │        └─────────────────┘
                  ▼
           ┌─────────────┐
           │  Advance    │
           │  Vehicle    │
           └─────────────┘
                  │
           ( Return )
```

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F i g . 15

```
                    (Interrupt)
                         |
              ┌──────────────────────┐
              ║ Running Course       ║
              ║     teaching         ║
              └──────────────────────┘
                         |
              ┌──────────────────────┐
              │ Calculate total      │
              │ distance ℓ from      │
              │ sensor 7             │
              └──────────────────────┘
                         |
              ┌──────────────────────┐
              │ Store ℓ as           │
              │ travel               │
              │     distance         │
              └──────────────────────┘
                         |
              ┌──────────────────────┐
              │ Store θ detected     │
              │ by sensor 8 as       │
              │ running direction    │
              └──────────────────────┘
                         |
              ┌──────────────────────┐
              │ add 1 to memory      │
              │ address              │
              └──────────────────────┘
                         |
                    (Return)
```

Fig. 16

Orientation Sensor subroutine (360°)

n = 1

rotation of sensor motor

input of rotational angle θ

θ ≧ n·θp? NO

n = n + 2

Stop Motor

Store A/D Converted Xn in address n-1

Store A/D converted Yn in address n

O ≧ 360? NO / Yes

Store final address Value N in address n+1

n = 0

Xmin=Xmax=Xo
Ymin=Ymax=Yo

Xmin ≦ Xn NO → Xmin = Xn
Yes

Xmax ≧ Xn NO → Xmax = Xn
Yes

Ymin ≦ Yn NO → Ymin = Yn
Yes

Ymax ≧ Yn NO → Ymax = Yn
Yes

n = n + 1

n > N ? NO / Yes

$\bar{X} = (Xmax+Xmin)/2$
$\bar{Y} (Ymax+Ymin)/2$

RETURN

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Fig. 17

quadrant judging
Subroutine

$X_n \geqq \bar{X}$ —NO→

Yes

$Y_n \geqq \bar{Y}$ $Y_n \geqq \bar{Y}$ —NO→

IV quadrant
$\theta_0 = 270°$

—NO→   Yes   Yes

| | I quadrant $\theta_0 = 0°$ | II quadrant $\theta_0 = 90°$ | III quadrant $\theta_0 = 180°$ |

| $X_n = X_n - \bar{X}$ | $X_n = X_n - \bar{X}$ | $X_n = \bar{X} - X_n$ | $X_n = \bar{X} - X_n$ |

| $Y_n = \bar{Y} - Y_n$ | $Y_n = Y_n - \bar{Y}$ | $Y_n = Y_n - \bar{Y}$ | $Y_n = \bar{Y} - Y_n$ |

RETURN

Fig.20

Section distance
Calculating routine

$n = 0. k = 0$

$\ell_k = y_k - y'_k$

store ℓ_k in address n

$k = k+1, n = n+1$ ←NO

is x_k maximum

Yes

clear address
$k+1$ et seq.

RETURN

Fig. 18

general form
calculating
subroutine

Search x min

x min $= x_0$? —No→ determine coordinate
transform function:
$\Phi(x_0 = x \min)$

$(x_n, y_n) \leftarrow \Phi(x_n, y_n)$

Yes

Search $X \max$

$n=0, k=0, N'=N$

$n=n+1, k=k+1, N'=N+3$

$x_n - x \min > d$ —No→ $x_n - x \min \leq d$ —YES→

Yes

$x_k = x \min + d$

No

$x_k = x_n$

$x \min = x \min + d$

$n=0 \quad N'=N+1$

$y_k = y_{k-1} + \left|\dfrac{y_n - y_{n-1}}{x_n - x_{n-1}}\right| d$

$y_k = y_n$

data in address
N' is transferred
to address n

Store x_k in address $N'+1$
Store y_k in address $N'+2$

Is data
in
address

No

$x_n = x \max$ —No→

Yes

Store $y_{n=N}$ in address $N+3$ $(y_{n=N} \rightarrow y_k = 0)$

$n=n+1, N'=N'+1$

$n=N-1, k=1, N'=N+3$

$n=n-1, k=k+1,$
$N'=N'+3$

$x_n > x_k$ —No→ $x_n < x_k$ —YES→

Yes

$y'_k = y'_{k-1} + \left|\dfrac{y_{n+1} - y_n}{x_{n+1} - x_n}\right| d$

No

$y'_k = y_n$

Store y'_k in address $N'+3$

$x_n = x \max$ —No→

Yes

Clear address $n+1$ et seq

RETURN

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Fig.19

$\Phi | x_0 = x_{min} |$: Coordinate transform function

$(\dot{x}_n, \dot{Y}_n) = \Phi(x_n, Y_n)$

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Fig.21A

Fig.21B

SPECIFICATION

Automatic running work vehicle

5 The present invention relates to a bulldozer, sprinkling truck, mower or like work vehicle which performs work during its passage while running over a course on a site and which is adapted automatically to run at least part of
10 its course without any driver aboard while carrying out its work.
 Such automatic running work vehicles as heretofore known include those for which a teaching/playback control system is used.
15 With such a system, the operator initially manually drives the work vehicle over the entire course to be run automatically subsequently, in order to sample the course as to the running distance, directions, etc. and store
20 the sampling information in a memory. For carrying out the subsequent work, the vehicle is automatically driven along the specified running course in an unmanned state according to the sampling information thus taught as
25 to the running course. Thus, the system involves the necessity of manually driving the work vehicle over the entire running course at least once and is therefore totally useless for the case where the work needs to be per-
30 formed only once. The system has another drawback in that the memory must store a very large amount of sampling information as to the running course.
 An object of the present invention is to
35 provide an automatic running work vehicle which is fully adapted for teaching playback control with the use of a compact device of small memory capacity.
 The automatic running work vehicle of the
40 present invention is characterised in that the work vehicle has means for teaching position data at the outer periphery of the entire area of a work site and thereby automatically producing a running course covering the interior
45 thereof, and means for causing the work vehicle to run the running course under steering control.
 The above system eliminates the need to store information as to the entire running
50 course and therefore achieves a great saving in the amount of use of the memory required for teaching playback control. Accordingly the work vehicle is fully adapted for teaching playback control for universal use although
55 incorporating a device of much reduced size.
 A further object of the present invention is to prevent the work vehicle from turning on the predetermined running course accidentally.
60 To this end, the work vehicle is provided with means for producing a running course which calculates and memorizes the running course distance for every running process on the basis of the width of the work of the
65 running course when the work vehicle goes to a place and back, and a distance sensor for detecting the distance of travel of the work vehicle and an orientation sensor for detecting the orientation data of the work vehicle, said
70 orientation data being detected and sampled every predetermined distance of travel while teaching the data of the outer periphery of the work site. Thus, while teaching travel of the work vehicle, an orientation data is taught
75 every predetermined distance and the form of the outer periphery of the work site is recognized from the orientation data and then the distance of a running course, i.e. the distance from a turning point to the next turning point
80 of the work vehicle, is newly set for the continuous reciprocal travelling through all the area in the work site, and then the work vehicle is so controlled and steered as to turn with every said distance so that whole of the
85 work site may be worked.
 Furthermore, where the work vehicle is provided with follower sensors for detecting the boundary between the worked area and the unworked area and is enabled automatically to
90 travel along the boundary, the following problem occurs, namely when the work vehicle cannot detect the boundary during a running course, automatic travelling is stopped.
 It is required under such a situation to
95 enable the work vehicle to travel automatically and continuously in the predetermined direction and to turn surely and automatically only at the correct point where the work vehicle should turn.
100 To solve such a problem it is advantageous to use the travel distance of every running course calculated by the teaching of the position data of the outer periphery of the work site.
105 To fulfil this object, the automatic running work vehicle of the invention is adapted to repeat a running travel reciprocatingly and has follower sensors for detecting the boundary between a worked area and an unworked area
110 for each travel. The work vehicle is characterised in that it is provided with a distance for detecting the running distance of its body, an orientation sensor for detecting the running direction thereof, and means for teaching the
115 running course of one travel by sampling the running direction detected by the orientation sensor every predetermined running distance detected by the distance sensor during the travel, and for steering the work vehicle based
120 on the information of the running course obtained by the teaching of the preceding travel when the follower sensors fail to detect the boundary for a predetermined period of time.
125 Because of the above feature, the work vehicle has the following great advantage. When the follower sensors become no longer able to detect the boundary of the running area during running, the vehicle runs auto-
130 matically based on the teaching information

obtained in the preceding travel, so that the vehicle can be driven automatically with good stability without deviating greatly from the specified running course.

5   The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is an overall side elevation showing an embodiment of automatic running
10   work vehicle provided with a mower;

Figure 2 is an overall plan view of the work vehicle;

Figure 3 is a diagram showing the structure of an orientation sensor;
15   Figure 4 is a fragmentary front view showing a follower sensor;

Figure 5 is a block diagram showing a control system;

Figure 6 is a diagram illustrating the con-
20   cept of teaching;

Figure 7 is a diagram illustrating the concept of conversion of coordinates;

Figure 8 is a diagram showing a specified running course;
25   Figure 9 is a flow chart showing an operation of the control system;

Figure 10 is a flow chart showing another operation of the control system;

Figure 11 is a flow chart showing another
30   operation of the control system;

Figure 12 is a flow chart showing a subroutine for calculation of the coordinates;

Figure 13 is a flow chart showing an obstacle detouring control;
35   Figure 14 is a flow chart showing a play-back control;

Figure 15 is a flow chart showing an interruption;

Figure 16 is a flow chart showing a subrou-
40   tine for an orientation sensor;

Figure 17 is a flow chart showing a subroutine for quadrant judging;

Figure 18 is a flow chart showing a subroutine of general form;
45   Figure 19 is a schematic view of a coordinate transform function;

Figure 20 is a flow chart showing a subroutine for calculating each of the course distances; and
50   Figures 21 (A) and (B) are diagrams each showing how to make a detour round an obstacle.

Referring to Figs. 1 and 2, a vehicle body 1 has a mower assembly 4 vertically movably
55   suspended therefrom and positioned between its front and rear wheels 2, 3. The vehicle body 1 further has arranged on opposite sides of its front portion follower sensors 101A, 101B, having the construction to be de-
60   scribed below, for detecting the boundary of a running area, i.e. the boundary between an unmowed area and a mowed area. Thus, the mower is steered along the boundary detected by the follower sensors 101A, 101B so as
65   automatically to run over a specified running

course.

The mower is further provided ahead of its body 1 with an obstacle sensor 102 of the non-contact type for detecting obstacles on
70   the running course.

Additionally, the vehicle body 1 has a fifth wheel serving as a distance sensor 6 for generating a pulse per optional unit of running distance I_o in order continuously to detect
75   the distance of travel of the vehicle body 1, and an orientation sensor 5 for detecting the running direction of the body 1.

Usually the front wheels 2, 2 are adapted to be steered rightward or leftward by a
80   hydraulic cylinder 105, (Fig. 5) by a predetermined amount based on the result of detection of the boundary by the follower sensors 101A, 101B or on the result of detection of an obstacle by the sensor 102.
85   Each of the follower sensors 101A, 101B comprises a pair of photosensors S_1, S_2 and S'_1, S'_2, (Fig. 4) of identical structure disposed ahead of each side of the mower assembly 4.
90   Fig. 4 shows the structure of the photosensors S_1, S_2 and S'_1, S'_2. A sensor mount frame 104 attached to the mower assembly 4 is fixed provided with substantially U-shaped sensor frames 103, 103 arranged side by
95   side laterally of the vehicle body 1. Each sensor frame 103 has a light-emitting element P_1 and photocell P_2 on the opposed inner sides thereof for detecting the presence or absence of grass to be brought into the space
100 therebetween with the travel of the vehicle body 1 in order to detect the boundary between the mowed area and the unmowed area.

It can be seen from Fig. 8 that when the
105 follower sensor 101A composed of the photosensors S_1, S_2 or the follower sensor 101B composed of the photosensor S'_1, S'_2 is in the unmowed area 17A, the vehicle is so steered for running that the outer photosensor S_2 or
110 S'_2 only of the other follower sensor is positioned in the mowed area 17B. Upon reaching a turning area 17C around the mowing area 17, the vehicle is turned toward the follower sensor which has been in the un-
115 mowed area 17A. The turning area 17C consists of an area mowed in advance by non-automatically driving the mower. Upon the arrival of the vehicle at the turning area 17C, all the four photosensors S_1, S_2 and S'_1, S'_2
120 constituting the follower sensors 101A, 101B detect the mowed area, indicating this arrival.

The follower sensors 101A, 101B are not limited to those comprising photosensors S_1, S_2 and S'_1, S'_2 but can be composed of other
125 sensors of the non-contact, contact or any other type.

The obstacle sensor 102 comprises four contact members 102a, 102b, 102c, 102d arranged ahead of the vehicle body 1 and
130 spaced approximately over the entire width of

the body 1, usually biased forward and each individually turnable rearward by contact with an obstacle, and switches S₃, ... provided at the base ends 102e, ... thereof for detecting
5 the turn of the contact members 102a, 102b, 102c, 102d, respectively.

The position where an obstacle comes into contact with the sensor 102 is detectable in four divided ranges corresponding to the oper-
10 ative positions of the switches S_3, ...

As seen in Fig. 3, the orientation sensor 5 comprises a toroidal core 7 having an exciting coil Co would thereon, and output coils Cx, Cy diametrically wound on the coil Co and inter-
15 secting each other at right angles. When the toroidal core 7 is subjected to an external magnetic field (geomagnetism) with a.c. current passed through the exciting coil Co, the output coils Cx, Cy generate a.c. signal vol-
20 tages in proportion to the external magnetic field. The a.c. signal voltages generated in the output coils Cx, Cy are amplified to a predetermined level and then converted to d.c. voltages Vx, Vy, the ratio of which indicates
25 an orientation.

The toroidal core 7 constituting the orientation sensor 5 is provided with rotating means A rotatably through 360° about a vertical axis P for correcting the difference in the magnetic
30 sensitivity of the output coils Cx, Cy in different orientations and enabling these coils to detect the running direction of the vehicle body 1 relative to a specified orientation.

The rotating means A comprises a nonmag-
35 netic bracket 8 having the toroidal core 7 fixed thereto, and a motor 9 for rotating the bracket 8 clockwise or counter-clockwise. A potentiometer PM is provided on the axis P for detecting the angle θ of rotation of the
40 sensor.

The distance sensor 6 generates a pulse per unit distance of travel of the vehicle body 1. A counter 10 counts up a specified number of pulses to detect a predetermined distance of
45 travel, l_0.

Next, a control device 11 will be described which serves as a general form of teaching device for calculating the general form of a work site from sampling information. The in-
50 formation is obtained by sampling a running course around the work site based on the detection signals from the orientation sensor 5 and the distance sensor 6 of the foregoing construction.
55 With reference to Fig. 5, the d.c. voltages Vx, Vy delivered from the orientation sensor 5 and serving as orientation detecting signals and the voltage V_0 given by the potentiometer PM and representing the angle of rotation of
60 the sensor 5 are fed through a signal detector 12 to an A/D converter 13, in which the voltages are converted to digital signals. The signals are fed to an arithmetic unit 15 of the control device 11 via an input-output interface
65 14. Every time the specified number of pulses

(corresponding to the predetermined travel distance l_0) from the distance sensor 6 have been counted up by the counter 10, the voltages Vx, Vy representing the orientation
70 data detected by the orientation sensor 5 are sampled and stored in a predetermined address area of CPU 15.

In order to correct, with respect to over orientation, the sensitivity with which the geo-
75 magnetism is detected by the orientation sensor 5, prior to the orientation sampling to be carried out every predetermined travel distance l_0 and also to recognize detected absolute orientations in terms of changes in the
80 running direction of the vehicle body 1 relative to the specified direction of the work site during travelling for teaching, average detection voltages $\bar{X}$, $\bar{Y}$ with respect to a reference orientation are calculated prior to the teaching
85 of the outer periphery of the work site, by rotating the orientation sensor 5 through 360° with the vehicle body 1 at a halt and sampling the detection voltages Vx, Vy every specified angle θ_0 (Fig. 16).
90 The control system will now be described for automatically controlling the running of the mower, based on the detection signals from the sensors 5, 6, 101A, 101B and 102 of the above described construction.
95 With reference to Fig. 5, the control system comprises CPU 15 the main portion of which is a microcomputer. The signals from the follower sensors 101A, 101B the obstacle sensor 102, the distance sensor 6 and the
100 orientation sensor 5 are fed to CPU 15 via an input interface 14A. Based on the signals from these sensors, CPU 15 performs an arithmetic operation and gives the result, i.e., control signals, to an output interface 14B to
105 cause an electromagnetic valve 106 to drive the hydraulic cylinder 105, which is an actuator, thus operating the front wheels 2, 2 and a speed change unit 107.

First, the operator manually drives the work
110 vehicle so as to make a round of the outer periphery 18 of the work site 17, (Fig. 6), so that lawn in the area of the cutting width d of the mowing assembly 4 may be cut, or drives the work vehicle to make a further round so
115 as to cut lawn in the area of the double width (2d) of the cutting width d. During the running, the detection voltages Vx, Vy from the orientation sensor 5 are sampled every predetermined travel distance l_0 from the start point
120 ST to obtain orientation data Xn, Yn as converted to displacement values relative to the reference orientation voltages, $\bar{X}$, $\bar{Y}$, and the data is stored in a predetermined address area of CPU 15.
125 After the teaching of the work site outer periphery 18, the vehicle body 1 is stopped temporarily at the start point ST or in the vicinity thereof, and the coordinates (x_n, Y_n) of the sampling points of the outer periphery 18
130 on the coordinate system having the start

point ST as origin are calculated by the following procedure, (Fig. 6, Fig. 7).

Stated more specifically, the items of orientation data Xn, Yn are compared with the reference orientation voltages $\bar{X}$, $\bar{Y}$ respectively to judge the quadrant of the running direction and calculate the orientation θ of the running direction with respect to the reference orientation (Fig. 17). The coordinates (x_n, y_n) of each of the sampling points are calculated from the orientation θ, the predetermined travel distance l_o and the coordinates (x_{n-1}, y_{n-1}) of the preceding sampling point and are stored in the same address area of CPU 15 as the orientation data x_n, y_n, whereby the orientation data x_n, y_n obtained for the outer peripheral teaching is replaced by the coordinate data x_n, y_n of the work site outer periphery (Fig. 12). The coordinates of the start point ST are preset as coordinates (O, O) and the coordinates (x_n, y_n) of the other sampling points are calculated in terms of distances from the reference coordinates (O, O) in x-direction and y-direction.

The sampling information of the teaching phase converted to the coordinate system with respect to the start point ST, as origin, by the above procedure is further converted by the following procedure to a coordinate system utilizing the cutting width d of the mowing assembly 4 as a unit for the coordinate system.

First, referring to Fig. 18, since it is desirable that the x-axis direction on the coordinate system is accorded with the travelling direction of the work vehicle at the starting point for the teaching operation, or in other words the minimum value x min of x-coordinate at the sampling point is X_o, when in the relation of x min = x_o, the coordinate system is rotated about the origin thereof in order to obtain the relation of x min = x_o. As the result, the coordinates (x_n, y_n), become new coordinates $(\dot{x}_n, \dot{y}_n) = \Phi| x_o = \text{xminl} (x_n, y_n)$ where the coordinate transform function is $\Phi| x_o = \text{xminl}$. When the coordinates $\dot{x}_n, \dot{y}_n$, are replaced by the coordinates x_n, y_n; x_n, y_n become the coordinates on the coordinate system which defines $x_o = x$ min, as shown in Fig. 19.

Thereafter, the maximum value Xmax and minimum value Xmin on the x-coordinates of the coordinates (x_n, y_n) of the sampling points are calculated again. Based on the minimum value Xmin, the coordinates (x_k, y_k), (x_k, y_k') corresponding to X values $x_k : x_k = \text{Xmin} + k \cdot_d$ increased by a distance of the cutting width(s) d from the minimum xmin are calculated by the interpolation method, and the resulting data is totally substituted for the data in the address area of the memory 16 in which the sampling point coordinates xn, yn are stored. Thus the general form of the work site is calculated and stored in terms of the coordinates (x_k, y_k), (x_k, y_k') which are directly usable

for mowing.

The data of coordinates (x_k, y_k), (x_k, y_k') thus calculated can be stored in a smaller memory area than the sampling information stored for the outer periphery teaching, so that the amount of the memory eventually used can be smaller.

Based on the coordinates (x_k, y_k), (x_k, y_k') corresponding to every cutting width d, the distance $l_1 \ldots \ldots l_k$ for each straight section of the running course is calculated from the coordinates (x_k, y_k), (x_k, y_k'), i.e. $l_k = y_k - y_k'$ (Fig. 20). Thus it is easy to calculate the information, such as the running course which is required, for example, for automatic steering in the mowing operation to be conducted after the teaching of the general form.

Thereafter, on the basis of the results of detecting the boundary by the follower sensors 101A, 101B, the front wheels 2, 2 are steered and the work vehicle starts to run under the follower control so as to run along the boundary between the unmowed area and the mowed area from the turning area 17C in the vicinity of the starting point ST and then automatically travels in the predetermined direction.

If while travelling under follower control, there is located an obstacle 17D on the running course between the turning area 17C and when the obstacle sensor 102 detects the obstacle 17D, an obstacle deviation or detouring control is carried out in preference to the follower control which is based on the detecting signals from the follower sensors 101A, 101B.

The obstacle detouring control will be described below (Fig. 13).

When one of the switches $S_3, \ldots$ of the obstacle sensor 102 is turned on upon detecting an obstacle, the follower control is interrupted, and the speed change unit 16 is operated to temporarily step the vehicle body 1. The switch S_3 actuated is identified in order to determine which of the contact members 102a, 102b, 102c, 102d has come into contact with the obstacle. If the contact member 102b or 102c in the center is in contact therewith, the vehicle body 1 is retracted a predetermined distance and then advanced and steered toward a given direction as shown in Fig. 21A. When the vehicle body is to be thus retracted temporarily, the data indicating the particular contact member in contact with the obstacle is temporarily stored in the memory to determine the detouring direction, and the vehicle is thereafter steered in the detouring direction immediately before it is advanced. The detouring direction determined is toward one side opposite the particular contact member concerned.

If only one of the outer members 102a, 102d has come into contact with the obstacle, the vehicle is advanced as it is steered toward a direction opposite to that member,

as shown in Fig. 21B.

After the vehicle has been brought into the advance travel for detouring around the obstacle, the vehicle is steered according to the
5 running course information obtained by teaching in the course of the preceding travel as will be described later, to automatically return to the running course before the detouring. The control by the follower sensors 101A,
10 101B is thereafter resumed automatically to drive the vehicle in the specified direction.

Further, the work vehicle is provided with a teaching function whereby the information as to each of the course runs by the vehicle
15 under the follower control as well as under the obstacle detouring control will be sampled and stored for teaching in the following manner.

There will now be described hereunder the
20 manner of the course teaching.

The running course sampling is an interrupt process (Fig. 15) which is initiated most preferentially in response to a pulse count signal emitted by the distance sensor 6 every predet-
25 ermined distance of travel, I_o, which is predetermined as the sampling interval for the running course.

With reference to Fig. 8, the overall control program is so designed as to sample and
30 store the running course information for every travel which is initiated upon the detection of the unmowed area 17A by one of the photosensors S_1, S_2, S'_1, S'_2 constituting the follower sensors 101A, 101B with the advance
35 of the vehicle body 1 from the turning area 17C into the unmowed area 17A shown in Fig. 8 and which is completed when the mowed turning area 17C is detected by all the photosensors S_1, S_2, S'_1, S'_2.
40 More specifically stated, when the vehicle body 1 starts running under the follower control from one end of the turning area 17C around the unmowed area 17A, a counter simultaneously starts counting up the pulse
45 signals from the distance sensor 6, and every time the vehicle body 1 has run the predetermined distance I_o, the running direction θ detected by the orientation sensor 5 at that time and the total distance I of travel after the
50 start of counting are stored in a specified memory area within the control unit 15' as teaching data obtained by sampling the running course. The running course is sampled and stored also when the vehicle is under the
55 obstacle detouring control by similarly storing the steering angle, i.e., the running direction θ, every time the vehicle has covered the travel distance I_o.

As seen in Fig. 8, the running direction of
60 the vehicle body reciprocatingly reverses from one travel to the next travel. In a subsequent travel, therefore, the running course information obtained by the teaching of the preceding travel is read out in an order reverse to the
65 storing order. Thus the data is retrieved from

the memory in response to the signals from the distance sensor 6 by reversely referring to the address concerned.

As described above, while the work vehicle
70 travels under the follower control by teaching each of the running courses, when one of the follower sensors 101A, 101B does not detect the unmowed area or cannot detect the boundary. After a predetermined period of
75 time has passed, the playback control takes place to cause the work vehicle automatically to run in the predetermined direction by advancing the work vehicle after forcibly steering the work vehicle to face the direction
80 turned 180° from the direction θ at the present point on the path of the running course between the turning area 17C.

Where there is a bare or turfless spot on the running course and when the follower sensors
85 101A, 101B detect no unmowed area 17A, namely the same circumstances as that in which the work vehicle should be turned, comparison is made between the actual distance I from the turning area to the present
90 point and one process of the running course distance I_1, I_2 ... I_k, previously calculated and memorized during the teaching of the outline of the work site, and as the result, when the actual distance I is smaller than the preset
95 running course distance I_1, I_2 ... I_k, including the range of a detectional error, the work vehicle is advanced automatically and forcibly under the steering control in the predetermined direction with reference to the running
100 direction data [I, θ] obtained in the preceding process as in the manner explained hereinbefore.

In this case, the arrangement may be modified so as not to effect a steering control on
105 the basis of the data obtained by the teaching in the preceding process, but to simplify so as to merely advance the work vehicle by preventing same from running under the follower control until the unmowed area 17A is de-
110 tected by one or both of the follower sensors 101A, 101B.

Further, only when both the follower sensors 101A, 101B detect the mowed area, i.e. the turning area 17C and the actual running
115 distance I in one process of travel is accorded with the preset running distance I_i (I = I_1 in first process; I = I_2, second process; I = I_k k−th process), the work vehicle is automatically steered to the utmost in the turning area 17C
120 and then the next process of travel starts under the follower control.

Also, when the obstacle detouring control is carried out during automatic running under the follower control, the running course after
125 detouring the obstacle 17D is revised or correct and then the work vehicle is automatically steered by means of the playback control to take the predetermined running course.

Thus, the running course data [I, θ] taught
130 in each of the processes of the running

course, are replaced by the running course
data [l, θ] newly taught in the present process
when the work vehicle 1 turns in the turning
area 17C, and then the vehicle runs along the
5 boundary under the follower control.
Fig. 9 is a flow chart showing the function
of the above mentioned CPU 15.
The orientation sensor in the above de-
scribed embodiment may be replaced by a
10 potentiometer which is mounted on the axles
of the front wheels 2, 2 to provide means for
detecting a steering angle, or it may utilize the
distance sensor 6 to detect the running direc-
tion of the fifth wheel instead of detecting the
15 steering angle of the front wheels 2, 2.
As described above, in the work vehicle
according to this embodiment, each of the
processes of the running course, which is
utilized for automatic steering control of the
20 work vehicle, is calculated and memorized by
teaching position data on the outer periphery
of all the work site. Then, in the actual
running after completion of the initial teach-
ing, only the position data of one process of
25 travel through which the work vehicle has just
passed, may be memorized and utilized for
the playback control (Fig. 14) when the fol-
lower control cannot take place. Thus, there is
no need to memorize all of the running course
30 data for surely and correctly controlling the
work vehicle.
Moreover, in this embodiment, in addition
to the construction which makes teaching of
the outer periphery of the work site for calcu-
35 lating each of the processes of travel of the
running course, there is provided the con-
struction for teaching each of the processes of
travel while actual travelling.
However, where the work vehicle does not
40 slip or get out of the predetermined direction
due to the good condition of the work site, it
is possible to control the work vehicle by
utilizing only the distance data of each of the
processes of the running course without the
45 follower control.
A simplified embodiment for working the
above control system will now be described.
A work vehicle body 1 has a mower as-
sembly 4 vertically movably suspended there-
50 from and positioned between the front and
rear wheels 2 and 3. The vehicle body 1
further has an orientation sensor 5 on a front
portion thereof for sensing the geomagnetism
and thereby detecting the running direction of
55 the body 1, and a fifth wheel connected to its
rear end and serving as a distance sensor 6
for continuously detecting the distance of tra-
vel of the vehicle body 1.
After completion of initial teaching of the
60 outer line of the work site, the work vehicle
starts mowing the turf. As the work vehicle
actually runs through the preset distance of a
process of the travelling course, the work
vehicle turns and continues the mowing work.
65 A flow chart for showing the function of

CPU 15, is Fig. 10.
As will be seen from the flow chart, the
work vehicle which may automatically travel
without the follower control, may be con-
70 structed using a small capacity of memory
and a simple program.
Furthermore, it is possible to provide such a
work vehicle which does not set the running
distance by the initial teaching, but carries out
75 teaching of position data of each of the pro-
cesses of the running course every time while
actual travelling and provides not only the
follower control, but also means for steering
the work vehicle to run on the basis of the
80 running course data taught in the preceding
course in the event that the follower sensors
detect no boundary for a predetermined per-
iod of time.
When the follower sensors are no longer
85 able to detect the boundary of the running
area during running, the vehicle runs auto-
matically based on the information of teaching
obtained in the preceding travel, so that the
vehicle can be driven automatically with good
90 stability without deviating greatly from the
specified running course.
This type of work vehicle will now be de-
scribed.
As in the first embodiment, the work
95 vehicle mowing the turf is provided with an
orientation sensor 5, a distance sensor 6,
follower sensors 101A, 101B, an obstacle
detecting sensor 6 and so forth. A control
system having a microcomputer as an essen-
100 tial element thereof is substantially the same
as in the first embodiment, but there is a
different flow in the control as shown in Fig.
11.
More specifically stated, when the vehicle
105 body 1 starts running under follower control
from one end of the turning area 17C around
the unmowed area 17A, a counter simultane-
ously starts counting up the pulse signals
from the distance sensor 6, and every time
110 the vehicle body 1 has run the predetermined
distance l_o, the running direction θ detected
by the orientation sensor 5 at that time and
the total distance l of travel after the start of
counting are stored in a specified memory
115 area within the control unit 15' as teaching
data obtained by sampling the running
course. The running course is sampled and
stored also when the vehicle is under the
obstacle detouring control by similarly storing
120 the steering angle, i.e., the running direction
θ, every time the vehicle has covered the
travel distance l_o.
As seen in Fig. 8, the running direction of
the vehicle body repeats a travel which is
125 reciprocatingly reverse from travel to travel. In
the subsequent travel, therefore, the running
course information obtained by the teaching
of the preceding travel is read out in an order
reverse to the storing order. Thus, the data is
130 retrieved from the memory in response to the

signals from the distance sensor by reversely referring to the address concerned.

Thus, it is similar to the first embodiment that the playback control or the obstacle de-
5 touring control is carried out while travelling.

When the vehicle body changes its direction at the turning area 12D, the running course information I, θ newly taught in the present travel is block-transferred to the memory area
10 storing the information of the preceding travel. The vehicle therefore runs along the boundary of the running area under follower control with the contents of its memory renewed from travel to travel.
15 In this way, the vehicle is automatically taught the running course information as to one travel only, so that a memory of greatly reduced capacity is usable for storing the running course information I, θ, while there is
20 no need for the operator to teach the running course.

Although the orientation sensor 5 of the above embodiment is adapted to indicate the running direction by detecting the geomagnet-
25 ism, as an alternative which is usable for detecting the running direction during teaching, is means for detecting the steering angle of the front wheel 2 or the angular deflection of the fifth wheel serving as the distance
30 sensor 6.

CLAIMS

1. An automatic running work vehicle for performing work while running, comprising
35 means for teaching position data on the outer periphery of the entire area of a work site and thereby automatically producing a running course covering the interior thereof, and means for causing the work vehicle to run the
40 running course under steering control.

2. A work vehicle as claimed in claim 1, wherein said means for producing a running course is so constructed as to calculate and memorize the running course distances of
45 every running process on the basis of the width of the work of the running course while repeating a reciprocating running process to perform work on the ground of the work site from one end of the work site to the other end
50 thereof, further comprising a distance sensor for detecting every running distance and an orientation sensor for detecting orientation information of the work vehicle, said orientation information being detected and sampled in
55 the predetermined running distance during the teaching travel.

3. A work vehicle as claimed in claim 2, further comprising follower sensors for detecting the boundary between a worked area and
60 an unworked area and generating signals so that the work vehicle may automatically travel along the boundary on the basis of the signals and turning of the work vehicle is carried out only under the condition that the memorized
65 distances are in accord with the actual dis-

tances detected per each running process by means of the distance sensor at real time.

4. Automatic running work vehicle, constructed arranged and adapted to operate sub-
70 stantially as hereinbefore described with reference to the accompanying drawings.